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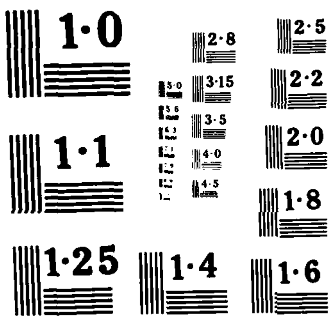

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Technical Report NAVTRASYSCEN 85-C-0069

FEASIBILITY STUDY FOR A STATIC AIRCRAFT FLIGHT

Charles Hightower

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FEASIBILITY STUDY FOR A STATIC AIRCRAFT FLIGHT

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THE FEASIBILITY OF EMBEDDING TRAINING SOFTWARE IN MODERN FLIGHT AIRCRAFT TO MAINTAIN PILOT PROFICIENCY WHILE DEPLOYED AS INVESTIGATED. CANDIDATE TRAINING SCENARIOS CRITICAL TO PILOT PERFORMANCE WERE IDENTIFIED. FEASIBILITY WAS DEMONSTRATED BASED ON CURRENT AND PROJECTED CAPABILITIES OF THE AYK-14 MISSION COMPUTERS PERFORMING THE WEAPONS AND NAVIGATION CALCULATIONS IN THE NAVY'S F/A-18 HORNET. IT WAS SHOWN THAT THE VERSION 6 AYK-14 COMPUTER WITH DUAL SINGLE CARD PROCESSORS (SCP'S) WOULD PROVIDE A SUITABLE HOST FOR TRAINING SOFTWARE. THE F/A-18 AVIONIC AND DISPLAY SYSTEMS ARE ALSO SHOWN TO SUPPORT THE SAFES CONCEPT. A NUMBER OF CANDIDATE SAFES IMPLEMENTATIONS ARE DEFINED AND ONE SELECTED FOR FEASIBILITY DEMONSTRATION.

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FEASIBILITY STUDY FOR A STATIC AIRCRAFT FLIGHT ENVIRONMENT SIMULATOR (SAFES)

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Excellent support and encouragement in this Small Business Innovation Research (SBIR) Program by Government Project Manager Denis Breglia also deserves special mention. Hopefully, he will see his support of fundamental efforts in embedded training lead to wide spread acceptance by the Fleet in the not too distant future.

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LIST OF ACRONYMS

ACRONYM	EXPLANATION
ADC	Air Data Computer
AEWTR	Aircrew Electronic Warfare Training System
BIT	Built-in Test
CAM	Camera
CBTS	Computer Based Training System
CIG	Computer Image Graphics
CRT	Cathode Ray Tube
CSC	Communication Systems Controller
DDI	Digital Display Indicator (also MDI)
EAU	Extended Arithmetic Unit
EGT	Exhaust Gas Temperature
F/A	Fighter/Attack
FCCA	Flight Control Computer A
FCCB	Flight Control Computer B
FLIR	Forward Looking Infrared
g	Gravity Constant
HARM	High Speed Anti-radiation Missile
HOTAS	Hands On Throttle and Stick
HSD	Horizontal Situation Display
HUD	Heads Up Display
I/O	Input/Output
ICC	Inter Computer Communcations
INS	Inertial Navigation System
K	Thousand
LDT	Laser Spot Tracker
M	Million
MC	Mission Computer
MDI	Multipurpose Display Indicator
MDRI	Multipurpose Display Repeater Indicator
MUX	Multiplexer
NAS	Naval Air Station
NATC	Naval Air Test Center
NATOP	Flight Training Manual for Naval Aviators
NTEC	Naval Training Equipment Center
NWC	Naval Weapons Center
OBCIG	On-Board Computer Image Graphics
OFP	Operational Flight Software
OPS	Operations per Second
PC	Pallet Computer
SAFES	Static Aircraft Flight Environment Simulator
SBIR	Small Business Innovaton Research
SCP	Single Card Processor
SMS	Stores Management System
TACTS	Tactical Aircrew Combat Training System
TDC	Target Designator Controller
TV	Television

1.0 INTRODUCTION

Training of Navy flight personnel is vital to successful mission accomplishment. This is aptly illustrated by analyzing U.S. fighter performance in actual combat with their Soviet counterparts over the last 30 years. The results of such an analysis (Ref. 1) shows that classical hardware performance superiority is one of the least frequent contributors to victory in the air. The lessons of history show instead that all of the winners and none of the losers had a pilot force of outstanding flying skill. Clearly a key to development and maintenance of a high level of pilot skill is frequent and realistic training. Flight simulation has proven to be effective and efficient in training Naval Aviators. An example of a modern flight simulator is the Weapons Tactics Trainer for the Navy F/A-18 Hornet strike fighter aircraft. This trainer projects computer generated images onto the inner surface of two 12 meter diameter domes, each of which surrounds a simulated Hornet aircraft cockpit. Hughes Aircraft developed and constructed this simulator under a Navy contract for $18.7 million. In September 1981, Hughes was awarded a $56 million Navy contract for two additional weapons trainers.

Although wide field view simulators play an important role in pilot training, they have some major drawbacks. Clearly, they are very expensive and only a relatively few can be built and maintained. Furthermore, due to their expense and the need to train as many student pilots as possible, experienced pilots have limited opportunity to practice in these trainers. It is obvious that pilots deployed on carriers or other duty stations cannot utilize such realistic and complex flight simulators to maintain their flight proficiency because of logistical and mission support factors.

In order to provide the experienced Naval aviator with a relatively inexpensive and effective flight simulator, regardless of his location, the potential of using computers and displays found on board modern aircraft should be considered. The cost effectiveness of Computer Based Training Systems (CBTS) which are gradually being introduced into military and civilian training courses also suggests that CBTS methodologies may further the usefulness of such embedded training devices. This study addresses the feasibility of a Static Aircraft Flight Environment Simulator (SAFES)[1] with CBTS capabilities. Such a static flight simulator should prove to be a useful extention of larger more complex ground-based wide field-of-view simulators and would complement in-flight embedded training simulators. Certainly, one of the most important aspects of training is to allow mistakes to be made without jeopardizing the pilot, his crew, or the aircraft. The only safe place to make these mistakes is where the aircraft is on the ground, not in the air.

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1. Dr. Andrew C. Cruce of the Naval Air Test Center appears to be one of the first individuals to recognize this potential, particularly in the F/A-18 (Ref. 2).

This study addresses the feasibility of providing flight simulation and training in a parked aircraft. Such a concept would embody low cost per training hour, realism, zero risk of flight assets, and negligible impact on airframe and mechanical system life. SAFES would provide the opportunity for training and maintenance of critical flying skills during extended personnel and flight asset deployment periods. With CBTS capability, instructor participation would not be necessary further reducing the cost of such training.

This study addresses the major issues associated with the SAFES concept. Training criteria candidates for incorporation into the SAFES system are developed in Section 2.0. The feasibility of utilizing the F/A-18 Hornet aircraft as a test bed for SAFES is presented in Section 3.0. Section 4.0 discusses a number of candidate SAFES implementation schemes and identifies an approach compatible with the current F/A-18 computer capabilities and architecture. An approach for the development of SAFES CBTS "scripts" is outlined in Section 5.0 based on two critical training tasks. Lastly, key SAFES feasibility issues that require experimental demonstration are the subject of Section 6.0.

2.0 TRAINING CRITERIA DEFINITION

The selection of tasks for SAFES training consideration should be based on the needs of Fleet F/A-18 pilots. This problem has been addressed by Coblitz (Ref. 3) specifically in the context of Onboard Computer Image Generation (OBCIG) for inflight training simulation. He suggests that training needs be prioritized by the criticality of the skill and the frequency of practice required to acquire and maintain the skill. Furthermore, since training of deployed forces is a major goal of any onboard CIG system, he recommends that emphasis be placed on tasks which have one of the following characteristics:

1. Frequent practice is required to maintain skill levels

2. The skill is a combat related skill not fully addressed in initial training

3. The skill continues to improve with prolonged training.

Colbitz identifies the most suitable applications and the least suitable applications of CIG based on interviews of experienced pilots and other experts. Consequently, the tasks he identifies as most suitable should be considered for SAFES, with consideration of the differences between static and inflight simulation.

2.1 Candidate SAFES Applications

Colbitz examined candidate OBCIG training in two categories (1) air-to-air combat tasks and (2) air-to-surface weapon delivery tasks. These tasks for fixed wing aircraft are summarized in Table 2-1.

Table 2-1 Candidate OBCIG Training Tasks
For Fixed Wing Aircraft

AIR-TO-AIR COMBAT TASKS

Combat Maneuvering
Air Intercept
Formation Flight
Air Refueling
Airborne Threat Avoidance

AIR-TO-SURFACE WEAPON DELIVERY TASKS

Visual Navigation
Visual Reconnaissance
Target Acquisition
Weapon Delivery
Take-off and Landing (Carrier)
Take-off and Landing (Fixed Base)
Low Level Flight
Low Level Navigation

Also considered for potential training are specific sensor related tasks such as those shown in Table 2-2.

Table 2-2 Candidate Sensor Related Tasks

Radar/Landmass - practice of general radar interpretation skills and/or premission familiarization of exact area to be overflown

Forward Looking Infrared (FLIR) -image interpretation and target recognition

TV Guided and TV Data Link Weapons - guidance control practice

Electronic Countermeasures - threat recognition and evasive action practice

Emergency Procedures - frequent practice is required to maintain proficiency

Cockpit Switchology - practice with computerized cockpit functions and capabilities

The last two items have been added to the list of sensor related tasks presented by Coblitz. These tasks are included in this study since it is recognized that SAFES is more than a flight simulator and has many elements of a Computer Based Training System (CBTS). Hence, SAFES can prepare the pilot for critical emergency situations and also help him to maintain his proficiency in manipulating the computer controlled systems and information available to him in the aircraft computer database.

2.2 Most Suitable Applications

Identification of the most suitable training applications for SAFES from those presented in the previous paragraphs must consider additional factors in addition to task criticality and frequency of practice required. Clearly, tasks which require high g forces or stressing aerodynamic performance cannot be simulated in a parked aircraft. In addition, limitations imposed by available aircraft displays, computer resources available, and computer/display interface problems must be considered. However, unlike in-flight OBCIG, SAFES is not constrained by the lack of an approved helmet mounted display in the aircraft for wide field of view simulation since flight safety is not a factor for a parked aircraft. The following sections describe those critical training tasks that are felt to be appropriate goals for SAFES implementation. The technical feasibility of actually achieving these goals within the context of the F/A-18 display and computer architecture is discussed later in this report.

2.2.1 Air Intercept

Air intercept operations are generally performed at long range using targets represented symbolically based on radar data. Since the display information is symbolic (i.e., created by vector graphic commands) it can be created by SAFES and displayed on the appropriate F/A-18 cockpit display for training purposes. This appears to be an excellent application for SAFES implementation.

2.2.2 Airborne Threat Avoidance

This is a critical combat task for which present training opportunities are limited. In normal operation, most of the visual threat information is displayed symbolically on the aircraft displays. The only exception is the outside-of-the- cockpit view of missile launches. However, Coblitz indicates that even without this out-of-the-cockpit view, the bulk of the necessary simulation can be presented on the in-cockpit displays. This application is ranked as an excellent OBCIG application and is clearly suitable for SAFES.

2.2.3 Target Acquisition

Another difficult and highly critical skill for which frequent practice can be helpful is sensor based target acquisition. In the case of SAFES, either radar or Forward Looking Infrared scenes would have to be presented realistically on the appropriate cockpit displays to achieve this goal. A helmet mounted display would be useful for target acquisition outside the cockpit although the extremely wide field of view required may be difficult to achieve with today's technology. Consequently, a reasonable SAFES goal is the creation of realistic sensor data superimposed with computed aided graphic symbology and alphanumeric data on cockpit displays.

2.2.4 Take-Off and Landing (Carrier)

Carrier landings are a difficult and dangerous task that requires continual practice. Surprisingly enough, the simulation of carrier landings is an area where the SAFES approach is clearly superior to in-flight OBCIG training, particularly night carrier landings. This stems from the fact that in-flight simulation of carrier landings would have to take place at altitudes where the air density and winds are similar to those at the surface of the ocean. This limits the maneuver to about 5,000 feet or less. This is not adequate altitude to recover from an inadvertent stall. Carrier landings in a parked aircraft, with the carrier image displayed calligraphically on a Heads Up Display (HUD), do not present this hazard since atmospheric conditions, sensor data, and aircraft response are simulated in a computer. Hence carrier landing training is ideal for SAFES.

Since a pilot who is trained successfully in landing at night will probably be successful during the day, daytime carrier landing training is considered to be less cost-effective than night training. Thus, night carrier landings are an excellent candidate for SAFES training.

2.2.5 Low Level Flight and Low Level Navigation

Low level flight training and navigation is applicable for SAFES training in scenarios where missions take place at night or in bad weather conditions. In such situations, the pilot relies completely upon cockpit displays. This is a skill of high criticality, requiring frequent practice to attain and maintain. The combined use of navigation data and sensor displays (e.g., radar terrain images) would be required for SAFES presentation.

2.2.6 Forward Looking Infrared (FLIR)

FLIR images are a good candidate for SAFES training since FLIR images of the same scene vary considerably with time-of-day and weather condition. During actual missions, many real FLIR images are available. Unfortunately, these images do not span the range of conditions, targets, and backgrounds necessary for systematic training of FLIR image interpretation and target recognition. Thus, SAFES training of these images is warranted.

2.2.7 TV Guided and TV Data Link Weapons

Images associated with TV Data Link guided weapons are in the visual spectrum and hence are less unusual for the pilot to interpret than radar or FLIR images. Target identification is also not as important in this case as well since the target has been identified by other means prior to the launch of the TV Data Link guided weapon. What is important is the practice of guidance control techniques for weapons that require pilot input. For TV weapons which do not require pilot guidance (e.g., the Maverick missile) after launch, training is required to correctly portray the lock-on and break-lock characteristics of the system. The frequency of practice required to master and maintain these skills is moderate, but present opportunities to obtain this practice are in some cases almost non existant. Consequently, SAFES is a likely source to provide this training experience.

2.2.8 Electronic Countermeasures and Electronic Warfare

Electronic Countermeasures and Electronic Warfare are good candidates for SAFES training since they are critical tasks not frequently practiced except at special training ranges such as NAS Fallon where the Tactical Aircrew Combat Training System (TACTS) is being integrated with the Aircrew Electronic Warfare Training Range (AEWTR). Display of threat symbology on the cockpit displays would aid the pilot in determining proper responses to types of threats in many different situations.

2.2.9 Emergency Procedures

The number of NATOP emergency procedures that must be committed to memory by the F/A-18 pilot are quite extensive. For example, even a relatively brief F/A-18 simulator exercise can include such things as engine fire on start, engine stall on takeoff, auxiliary power unit failure, generator failure, loss of Flight Control Computers and systems in various combinations, engine fire in flight, single engine failure, INS failure, etc. It would seen likely that review of these procedures presented on the aircraft cockpit displays would be more effective than review of the NATOP document from time to time.

2.2.10 Cockpit Switchology

The F/A-18 cockpit and weapon systems were specially designed for one pilot operation. Because of this, nearly all important systems are controlled by switches on the Hands On Throttle and Stick (HOTAS). This includes selection of menus on the cockpit displays and selection of items. In many ways the F/A-18 computer display system resembles a large data base about the aircraft status. For example, emergency procedures and the status of the digital flight control system can be called up by the pilot. As with any data base system, constant exercise of the query skills is necessary if the data base is to be used efficiently. In the F/A-18 cockpit this is much more important since the pilot's life and mission may depend on the rapid use of stored information. SAFES would be an excellent way for the pilot to maintain and exercise these skills

The importance of this function will increase significantly in tomorrow's aircraft. Tomorrow's pilot could find himself faced with too much information unless information is integrated into common displays. Continued practice and intimate familiarity with this information will be an absolute necessity. SAFES will be an excellent means for achieving the facility necessary to survive in this environment.

2.3 Candidate Training Scenario Ranking

Given the need to provide critical training to deployed pilots, the previously discussed tasks have been ranked in order of relative importance. This ranking is shown in Table 2-3.

Table 2-3 Candidate Training Scenario Ranking

1. Night Carrier Landing
2. Air-to-Air Threat Avoidance
3. Electronic Countermeasures and Electronic Warfare Sensor Environment
4. Air-to-Ground Target Acquisition
5. Air-to-Ground Weapons Delivery
6. Sensor Based Low Level Flight
7. Sensor Based Low Level Navigation
8. Infrared Sensor Environment
9. TV Link Sensor Environment
10. Emergency Procedures
11. Aircraft Cockpit Switchology

These training tasks should serve to guide the development of the operational SAFES. In addition, and prior to the development of an operational SAFES, a number of these scenarios should be selected and the SAFES concept demonstrated before entering a major development phase.

3.0 F/A-18 SAFES TECHNICAL FEASIBILITY

The F/A-18 Hornet represents a considerable step forward in the application of integrated controls and computer controlled displays to the reduction of pilot workload and enhancement of mission success. The F/A-18 cockpit features four multipurpose cathode-ray displays driven by two mission computers, an integrated up-front control, and numerous control functions on the Hands On Throttle and Stick (HOTAS) controls. It has been estimated that nearly 90% of the pilot's activities are carried out based on the information displayed on the multipurpose cathode-ray displays. These multipurpose displays , in conjunction with the Head Up Display (HUD), provide the pilot with all essential flight information for air-to-air, air-to-surface, and navigation phases of the mission (Ref. 4). The displays include two Multipurpose Display Indicators (MDI's), a Horizontal Situation Display (HSD) or Multipurpose Display Repeater Indicator (MDRI), and a Head-Up Display (HUD). Figure 3-1 shows these displays laid out in the F/A-18 crew station along with the Hands On Throttle and Stick (HOTAS) and other instrumentation. A typical MDI display with calligraphic information (pitch ladder) and digital radar (air-to-air) information superimposed is shown in Figure 3-2.

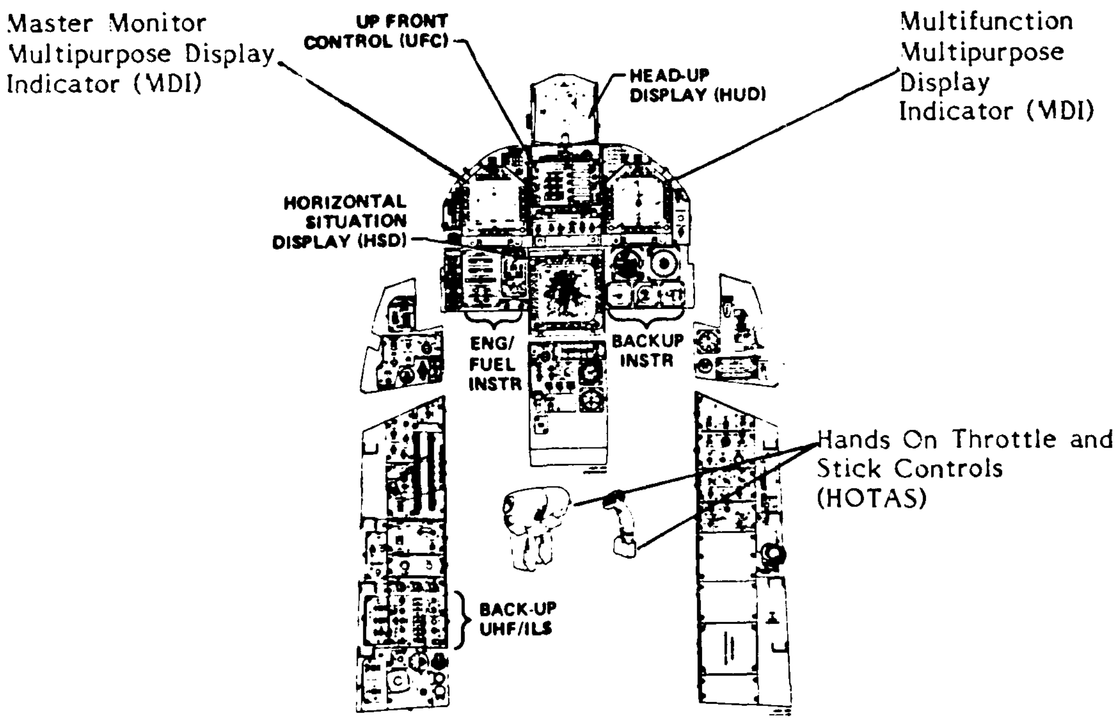


Figure 3-1 F/A-18 Cockpit Display Layout and HOTAS

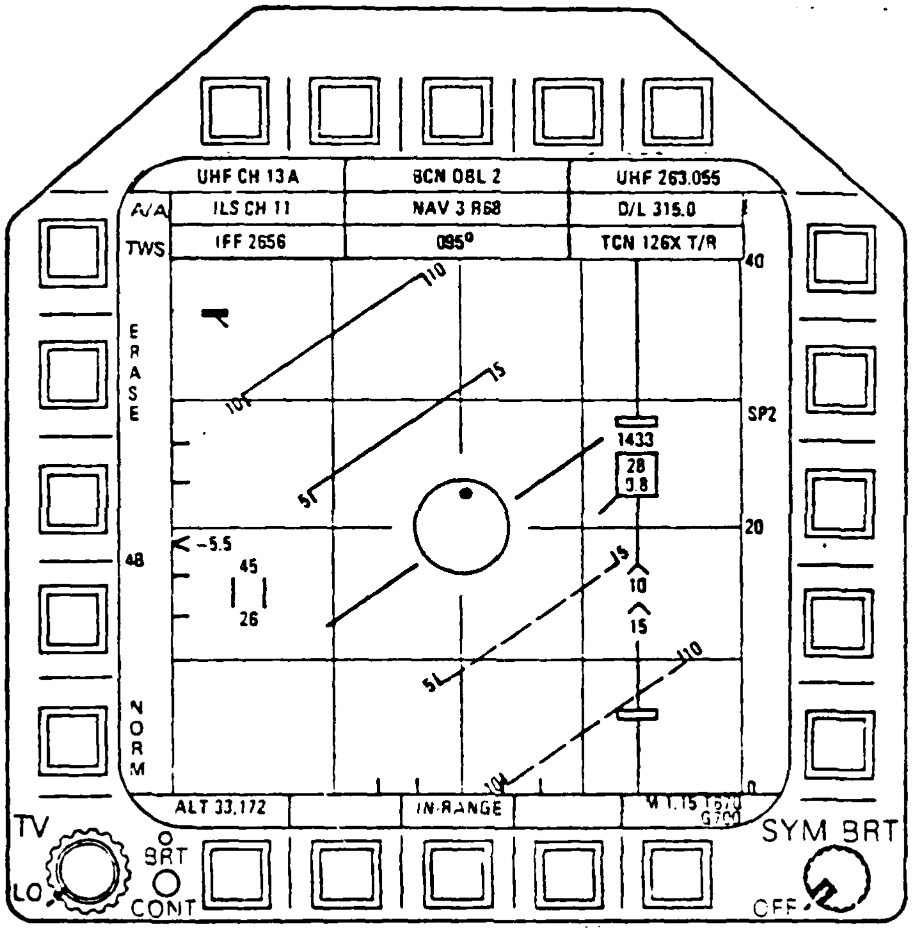


Figure 3-2 Typical MDI Display Presentation

Because of the sophistication of the F/A-18 crew station it appears possible for it to also serve as a training simulator for maintenance of pilot proficiency when the pilot is on duty station and far removed from access to conventional flight simulators or conventional flight training programs. The key technical issues associated with using the F/A-18 as a training platform are (1) presenting training simulation information to the multipurpose displays, (2) sensing the pilot's flight control commands (throttle, pitch, roll, and rudder), (3) sensing other pilot control inputs (particularly, the control commands located on the Hands On Throttle and Stick (HOTAS) controller), and (4) ensuring other aircraft functions not required for training are disabled (e.g., gear retraction, radar, armament, etc.). SAFES training will take place in the F/A-18 while it is parked on the ground or deck of a ship and not in flight. A very important groundrule for the training system besides being an effective trainer, is that it not adversely affect the operational readiness of the aircraft or pilot because of its use.

From a technical viewpoint, the parked aircraft with embedded training capability is attractive since the on-board computers can be augmented by more powerful externally located computers coupled into the F/A-18 crew station via a readily accessible 1553A data bus connector mounted in the nose wheel compartment. This unique feature permits the aircraft to be quickly disconnected from the training computer(s) and immediately returned to flight status. In addition, video information can be sent to the cockpit display via the FLIR connection and connectors mounted in the wing weapon pods normally used for TV guided weapons.

3.1 F/A-18 Cockpit Display Capability Overview

The architecture of the F/A-18 cockpit display system consists of two AYK-14 computers which provide control and display signals to the cockpit displays. These computers are tied to the various displays through a MIL-STD-1553A dual serial data bus. The cockpit display data flow is illustrated in Fig. 3-3. Each MDI exchanges information with either of two aircraft computers, designated as Mission Computer 1 (MC 1) or MC 2, and receives information from the radar, the Stores Management Set (SMS) and HOTAS control signals (referred to as "throttle" in the figure).

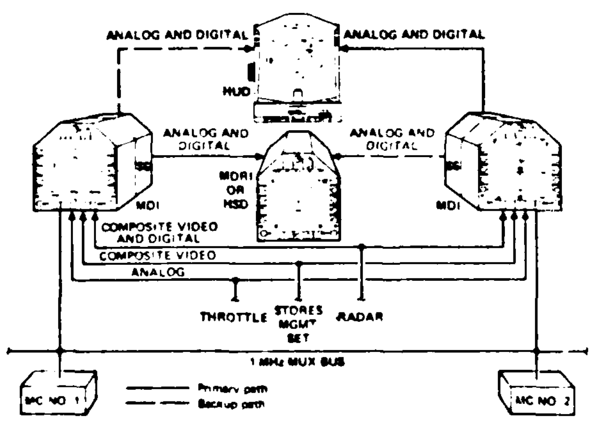


Figure 3-3 F/A-18 Display Information Communication Block Diagram

3.1.1 Radar Information

Radar information in the form of composite video and digital vector graphic information is sent directly to the MDI's. The radar composite video information is used to generate raster type displays of air-to-ground information (useful for bombing missions and navigation fixes). The radar serial digital information contains air-to-air information and is displayed in vector (i.e., stroke) format on the MDI's. MDI symbology that can be displayed under radar command in the vector mode is shown in Appendix B.

3.1.2 Stores Management Set (SMS) Information

The Stores Management Set (SMS) furnishes composite video information derived from any of the TV weapons or sensors carried aboard the F/A-18. These include the Forward Looking Infrared (FLIR), the Walleye or Maverick, and additional weapons which may be added.

3.1.3 HOTAS Throttle Mounted Information

Throttle mounted force controllers and switches activated by the pilot's fingers are used to position target designators on the displays and to control radar parameters. These switches allow the pilot to control weapons, sensors, and displays during time critical portions of the attack while maintaining full control of the aircraft. The three primary HOTAS switches are the Weapon Selector and Auto Lock-on selector on the stick, and the Target Designator on the throttle. The Target Designator Control (TDC) on the throttle is a force controlled switch which moves the appropriate designator symbol on the displays in any desired direction.

3.1.4 Display Mode Selection

Each of the multifunction displays have 20 pushbutton switches around their periphery. The display is formatted such that when sensor data is called up, a quarter inch strip of the perimeter of display is available for display of the primary controls for that sensor.

3.1.5 Flight Control Signals

In addition to the above information, aircraft control information including stick, rudder, and throttle positions will be required by SAFES for simulation of aircraft response to pilot inputs based on displayed information.

3.1.6 Other Information

Other information such as avionic device status and feedback, control data, etc. are needed for flight simulation maintenance.

3.2 SAFES Display and Pilot Input Sampling Requirements

In order for SAFES to function as an efficient training simulator it must be able to receive the control signals mentioned above and provide the appropriately formatted information to the displays. Table 3-1 summarizes these requirements.

Table 3-1 SAFES Display Signal Format Requirements

Output Display	Source	Description
Composite Video	Radar	Air-to-Ground
	SMS	TV Weapons, FLIR
Digital Video (Vector Graphics)	Radar	Air-to-Air
Alphanumeric Video (Character Display)	MC1 and MC2	Monitor Functions
Input Data Format	**Source**	**Description**
Analog	HOTAS	Cursor Control Position
Digital Serial	Radar	Air-to-Air
Analog	HOTAS	Target Designator Control, Weapon Selector, Auto Lock-on Selector
	Stick and Rudder	Flight Control Signals
	Throttles	Engine Thrust Signals
	Other Flight Data	Device Status, Control Data, etc.
1553 Serial Digital	MC1/MC2	Mission Computer Communication Information

It should be noted that composite video information is not displayed on the HUD.

3.2.1 SAFES Generation of Alphanumeric and Vector G hic Display Signals

Generation of simulated alphanumeric and vector graphic display information for the F/A-18 displays has been demonstrated at the Naval Air Test Center (Ref. 5, 6, and 7). However, this demonstration has been limited to only display information normally sent to the MDI's from the MC's via the MUX bus which excludes both digital radar information display and composite video images. In this section, it is shown how the digital radar information can be simulated by commands available to the MC's for transmission over the 1553 A MUX bus. The following section (3.2.2) discusses injection of simulated composite video imagery into the F/A-18 MDI's.

NATC has two F/A-18 cockpit simulators used to validate software modifications and determine weapon system performance. The software validation simulator does not use actual F/A-18 display hardware. Instead, alphanumeric and vector graphic information are displayed on commercially available CRT's with software drivers simulating the flight displays. Of more importance to SAFES, is the weapons performance simulation work at NATC, using an actual F/A-18 aircraft. The aircraft had been used for fatigue tests and was not flight worthy. The aircraft had an SMS, two Mission AYK-14 computers, Communications System Controller (CSC), and controls and displays (Ref. 8). The aircraft lacked flight computers so their functions were simulated with laboratory (VAX 11/780 and PDP 11) computers. The laboratory computers were connected to the 1553A buses on board the aircraft through a connector in the nose wheel area. Engineers then flew the aircraft through various weapon delivery profiles based on computer generated data presented on the aircraft displays. HOTAS flight control signals were generated from potentiometers installed on the throttle and stick since the lack of flight computers (not Mission Computers) precluded flight control signals from being placed on the 1553 bus and sensed by the laboratory computer. This configuraiton was used to successfully test the SMS software. The fact that the on board displays and controls were successfully used during the tests demonstrates the validity of using an external source for driving the cockpit displays.

The transfer of graphics information from the Mission Computers to an F/A-18 display is done over dual one megahertz 1553A multiplex buses. The bus exchanges data in a simplex manner using a self-clocking bi-phase code with 20 microseconds required for each word. Each word-time consists of 3 microseconds for a synchronization waveform followed by 16 data bits and concluded with a parity bit. Thirty-two message types are possible for each unit on the MUX bus. All display management is accomplished over this MUX bus.

There are 19 commands used to manage information transfers and moding between the MC's and the MDI's over the MUX bus (see 1553 A bus MDI input, labled MUX BUS in Figure 3-4 for the interface between these devices). Of these commands four are used to transmit Display Processor instructions and instruction sequences from the MC's to the MDI's. There are a maximum of 32 instruction op codes available that can be used to cause the display processor to generate various alphanumeric characters (see Appendix A) and special symbols (conics, pitch ladders, etc.) via the symbol generator in the MDI. Currently 30 of these op codes are in use (see Appendix B).

Note the input to the box labled PERIPHERAL I/O in Figure 3-4 from the radar. This information normally comes from the radar system and is used for display of air-to-air vector graphic information. The data supplied over the radar digital bus is interpreted by the display processor as if it were an MC generated radar alphanumeric instruction. This instruction can be used to generate any of the alphanumeric characters in shown in Appendix A, as well as the six unique symbols used for radar display representations (e.g., B sweep, acquisition symbol, azimuth carat, elevation carat, target symbol 1, and target symbol 2). Since any of the alphanumeric characters or unique symbols used for radar data display could be duplicated with the various instructions allowed in MC generated

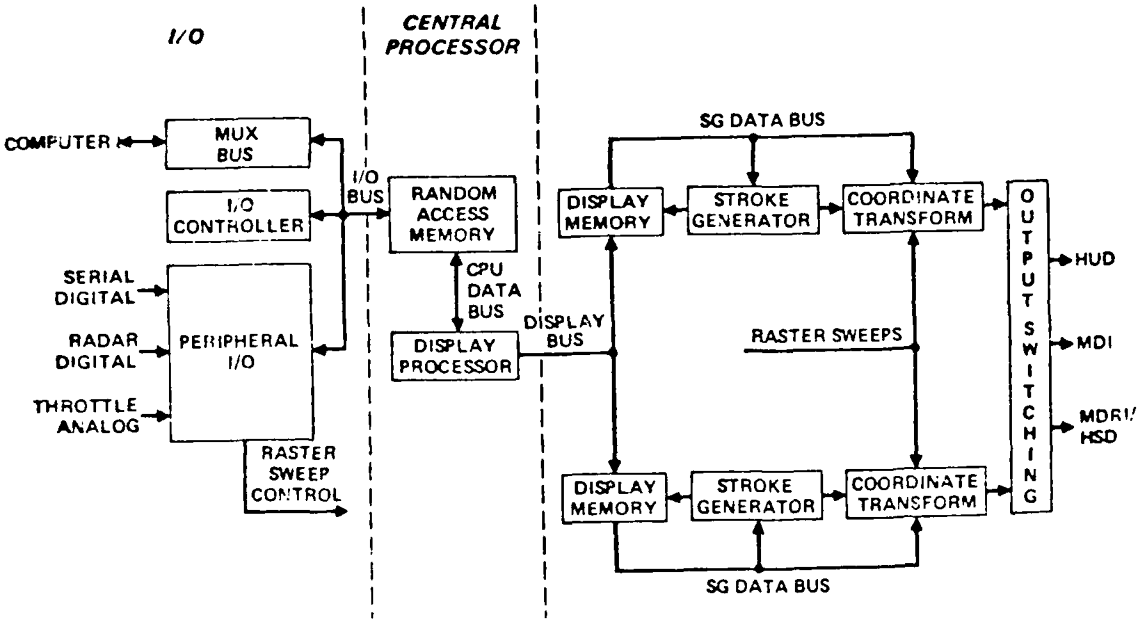


Figure 3-4 MDI Block Diagram Showing I/O Functions

instruction sequences, even without using the radar alphanumeric instruction, it appears feasible to simulate (air-to-air digital) radar displays with a display program generated by an MC and transmitted to the appropriate MDI over the MUX bus.

The THROTTLE ANALOG inputs to the PERIPHERAL I/O box control cursor location for interactive graphic operation between the pilot and computer. This information is received directly from the HOTAS switches and force controls. This information is placed on the 1553A bus for Mission Computer response. SAFES would sense these commands in the same way.

Thus, based on NATC work and the richness of graphic commands available to the MC, it appears that SAFES can be made to produce realistic alphanumeric and vector graphic information on the F/A-18 cockpit displays using the 1553A bus as an input gateway for display commands and data words and also receiving pilot display control commands from the same bus.

3.2.2 SAFES Generation of Composite Video Display Information

It was shown in the previous section how alphanumeric and vector graphic information can be transmitted to the cockpit displays via the 1553A MUX bus with little technical risk. A greater challenge is the creation and display of composite video images on the cockpit displays. The HUD is the only display which does not receive composite video input for display. The source of composite video information is either the radar (in air-to-ground mode) or from the SMS TV weapon systems or the FLIR.

Each display is capable of accepting composite video inputs having raster lines per frame ranging from 511 to 875. TV weapons have 484 active lines while radar signals have 512 active lines. FLIR imagery has 808 active lines per frame. TV composite video signals conform to the RS170-525 line standard. The radar composite video signal is a modified RS-343A 675 line format and the FLIR signal is a modified RS-343A 875 line format (Ref. 9).

In order for SAFES to send composite video to the cockpit displays, a suitable location must be found in the radar and SMS systems to inject the SAFES training composite video signals. Discussions with NWC personnel at China Lake, California indicate that it is possible to connect an external video signal to the SMS via weapon pod connectors normally used for TV guided weapons and possibly via a FLIR connection. The raster video signals introduced into the SMS via these connectors can be routed by computer control to the desired display. The external signals can represent radar imagery in the ground mapping mode as well as FLIR and TV images. If a FLIR port is used, no degradation in image quality will occur since all other composite sources utilize fewer lines per frame than the FLIR signals. However, if composite video is input through a TV weapon port, FLIR images injected into this port may suffer some degradation due to the loss in line resolution. The extent of this degradation (808 displayed lines for the FLIR versus 484 lines for the TV weapons) on the pilot's interpretation of simulated FLIR images should be investigated to determine if this will be a significant problem. This will only be a problem if a FLIR port is unavailable.

3.3 F/A-18 Mission Computer Memory Size and Timing Analysis

The F/A-18 aircraft avionics systems are controlled by two mission computers (MC's). One mission computer (MC 1) performs navigation functions and the second (MC 2) performs weapon delivery computations. Both computers have a capability to back each other up. The following paragraphs describe sizing and timing information for the two mission computers. This information is needed to determine the feasibility of using the MC's for embedded training software in Section 4.0 of this report.

3.3.1 AYK-14 Memory Requirements

The Version 5 AYK-14 computers used for MC 1 and MC 2 in production F/A-18 aircraft to date have 256 Kbytes (128 K 16 bit words) of core memory expandable to 512 Kbytes (256 K 16 bit words).

According to F/A-18 program office personnel at the Naval Weapon Center at China Lake, California the Navigation computer (MC 1) Operational Flight Program (OFP) software occupies all but 34 Kbytes (17 K 16 bit words) of the existing core memory. The Weapon computer MC 2 has 52 Kbytes available (27 K 16 bit words). The memory utilization of the current AYK-14 mission computers is shown in Table 3-2.

Table 3-2 AYK-14 Mission Computer Memory Utilization

Computer	Free Memory	Percent Used	Percent Unused
MC1	256Kbytes	87%	13%
MC2	256Kbytes	80%	20%

3.3.2 CPU Utilization

The utilization of the Version 5 AYK-14 processing resources to perform the necessary computations is driven by the need to provide a basic cycle time so that graphic display data does not flicker on the cockpit displays. The F/A-18 Operational Flight Program (OFP) software operates on a fixed major frame time during which I/O and other computations must be performed. The basic frame time is about 50 milliseconds for each mission computer. The mission computers operate in parallel. According to NWC and NATC personnel familiar with the OFP running on the Version 5 AYK-14, the computational cycle time has virtually no room for additional operations. Its operation is nearly at 100% capacity in its current configuration. Table 3-3 provides an estimate of how the OFP software modules in MC 1 are allocated within the major frame time of 50 milliseconds.

Table 3-3 F/A-18 Software Frame Time Allocation Estimate

MC1 SOFTWARE MODULE	PERCENT	TIME (MS)
1. Navigation	6	3
2. Engine Monitor	2	1
3. Data Link	9	4.5
4. Avionics BIT	2	1
5. Navigation HUD	5	2.5
6. Self-Test	2	1
7. Navigation Control and Displays	32	16
8. Inflight Monitor and Record	9	4.5
9. Non-Avionics BIT	1	0.5
10. Support Controls and Display	32	16
11. MC 2 Backup	-	-
Total	100	50

3.3.3 Near Term Improvements in AYK-14 Memory and Performance

The Version 5 AYK-14 is undergoing a planned product performance improvement program which will result in a Version 6 AYK-14 in the near future. Version 6 AYK-14 computers will have 512 Kbytes of core memory with an additional 512 Kbytes of EPROM. The Version 6 computors will include Dual Single Card Processor (SCP's) which are substantially more powerful than the existing Version 5 AYK-14 single CPU. The Version 6 computer includes includes hardware implementation of trigonometic functions and floating point arithmetiic operations. The Version 6 will also contain additional 1553 A and B bus ports. Table 3-4 illustrates the improvement in performance obtained in the Version 6 SCP when floating point trigonometric functions are performed in hardware as opposed to software fixed point (integer) operations as is currently done in the Version 5 AYK-14.

Table 3-4 AYK-14 Version 6 Single Card Processor Timing Data Improvement

FUNCTION	SCP (FLOATING POINT) Microseconds	SOFTWARE (FIXED POINT) Microseconds
Sine	20.2	175
Cosine	22.7	175
Arcsine	24.5	425
Arccosine	24.5	425
Arctangent	16.9	200
Exponential	30.9-32.0	150
Natural log	19.4	200

The performance shown in Table 3-4 for the SCP is similar to that which can be achieved with an Extended Arithmetic Unit (EAU) module available for earlier version AYK-14 computers which have room for the EAU module. Unfortunately, The Version 5 AYK-14 chassis as configured for the F/A-18 does not have room for this module upgrade. Based on the information contained in Table 3-4, it is reasonable to conclude that the AYK-14 upgrade program will allow the SAFES software and capabilities to continually increase in scale and magnitude. The SAFES software for the Version 5 computers will probably have to be reduced in scale to accommodate its limitations. However, the Version 6 computer will provide an extremely powerful host for SAFES software.

3.3.4 Serial Data Bus Utilization

The 1553 A serial twisted shielded pair redundant data buses in the F/A-18 transmit data at a rate of 1 MHz. The mission computers act as bus controllers and thus control data flow on the buses. Personnel at NWC and NATC have indicated that the bus transfer rate utilization is about 50% for the current OFP software. This indicates that there is adequate MUX bandwidth available for SAFES communication and message transmission.

3.3.5 F/A-18 Software and 1553 Bus Architecture

The memory and timing utilization factors discussed in the foregoing paragraphs exist within the computer and bus architecture shown in Figure 3-5. The various OFP software modules residing in each mission computer are shown in the figure. Note MC 1 has 12 different modules in addition to its database and MC 2 backup module. MC 2 has six modules in addition to its database and MC 1 backup module. The various avionic systems and the 1553 A bus interconnections are also illustrated. Access to the Channel 1 and 2 1553 A buses is available to the external environment through a connector located in the nose wheel housing area.

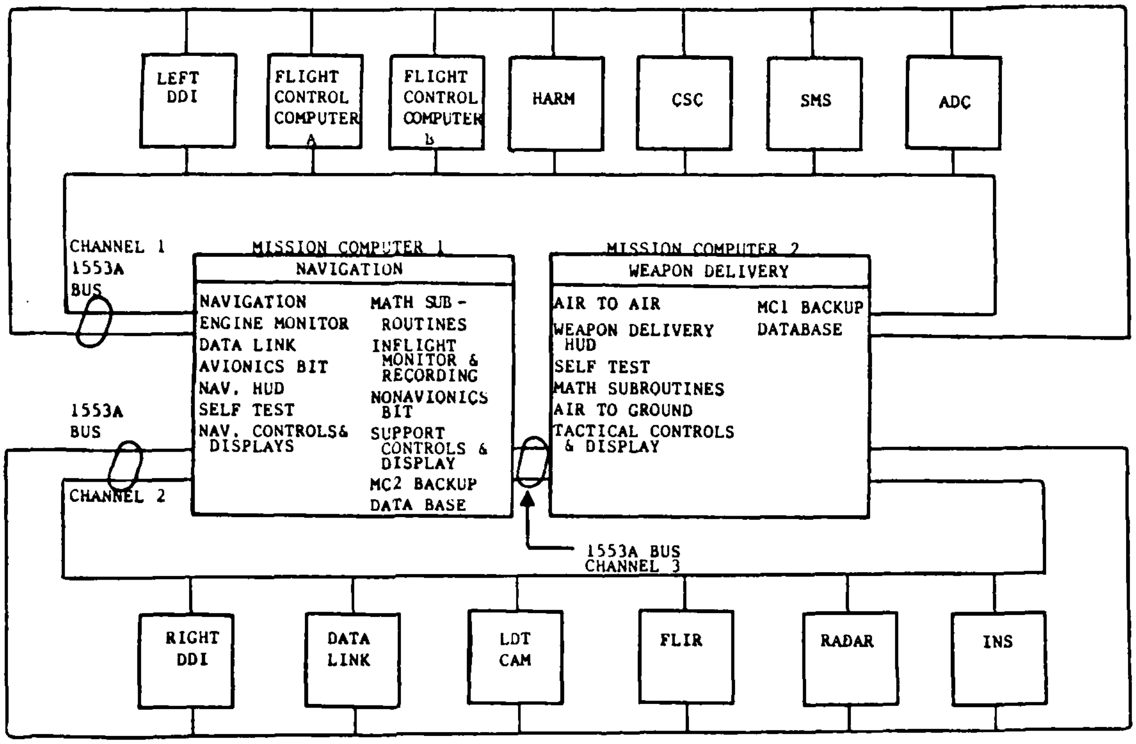


Figure 3-5 F/A-18 Mission Computer Software Organization and Architecture

OFP software is loaded into each mission computer through a separate serial data port located on each computer by special ground support equipment. Access to these ports is through hatches near the rear of the aircraft. It takes about five to 10 minutes to load the OFP software and another 10 to 20 minutes for the pilot to verify proper operation (the ground support equipment also verifies as it loads). It is also likely that OFP software can be loaded via the serial 1553 A bus so that aircraft hatch opening can be avoided.

3.4 Summary of SAFES Feasibility

The investigation summarized in the previous paragraphs leads to the conclusion that the F/A-18 will be an excellent candidate for introducing the SAFES concept to Fleet personnel. It has been shown that the MC's can present SAFES training information to the MDI's including digital radar symbology and composite video simulations of various kinds (FLIR, TV weapons, etc.). With the impending introduction of the Version 6 AYK-14 computer into Fleet F/A-18 aircraft, the probability of SAFES software successfully utilizing this resource in a meaningful way is greatly enhanced. The pilot's flight control commands can be sensed by SAFES software via the information placed on the 1553 A MUX bus by the Flight Computers. Other display and weapon selection inputs on the HOTAS can be sampled in the same way. It is anticipated that F/A-18 systems not needed for SAFES (e.g., radar, INS, etc.) can be powered down so they will not disturb SAFES operation. Finally, it appears that the SAFES physical interfaces to the aircraft are quite simple and would not interfere with returning the aircraft to operational status in a short time. Likewise, SAFES software could be replaced with the OFP software in a few minutes using 1553 A MUX bus loading. Thus no outstanding problems with incorporation of a SAFES capability in the F/A-18 have been identified.

Operationally, SAFES would be embedded in an aircraft located in a convenient location serving both the F/A-18 tactical mission and training role. Such locations include carriers, remote landbases, or bases needing inexpensive training to augment existing facilities. SAFES simply requires an unused aircraft for a short time (one or more hours). The SAFES aircraft could have just returned from a mission, be awaiting repairs, storage, or even in the middle of certain phases of mision preparation. SAFES external hardware is projected to be compact and mobile, easily approaching the parked aircraft on the hanger or flight deck. The aircraft must be connected to an external power source to power the electrical systems required for SAFES operation. All mechanical, hydraulic, and nonelectrical systems are rendered inoperative by the pilot or the maintenance crew by selective circuit breaker deactivation to prevent accidental gear retraction, missile firing, or radar activation. This also extends airframe and system lifetime during the training operation. The SAFES pallet computer 1553 A MUX bus interface is connected to the aircraft through the test connector in the nosewheel compartment and the video lines connected to the weapons pod connectors. SAFES software is loaded into the Mission Computers via the 1553 A MUX bus or the AYK-14 maintenance port. After a brief test of the SAFES software and video simulation system, training is initiated.

The pilot will be able to interactively select prestored training scenarios, rerun previous situations, or create new situations to match his current interests and requirements. The pilot will then initiate SAFES operation and begin a training session. After the training session is completed, the pilot will receive an evaluation of his performance and can replay portions or all of the session as he chooses. Returning the aircraft to flight status is simple and consists of powering down the F/A-18 electrical and electronic systems needed for SAFES and disconnecting the SAFES interfaces to the aircraft. The OFP software can then be reloaded into the aircraft core memory using standard maintenance procedures and equipment.

4.0 SAFES CANDIDATE CONCEPTS EVALUATION

This section presents five candidate SAFES configurations and describes each configuration's advantages and disadvantages. These candidates are shown in Table 4-1.

Table 4-1 Candidate SAFES Configurations

1. Onboard Stand-alone
2. Onboard With Pallet
3. Pallet System without Mission Computers
4. Pallet System with Mission Computers
5. Onboard Built-In Test

The section concludes with a description of the selected SAFES configuration that will be used to determine which elements require proof of concept in the follow-on to this study.

4.1 Onboard Stand-alone

The Onboard Stand-alone SAFES candidate consists of a new set of software for the Mission Computers that would include condensed Operational Flight Program (OFP) software as well as a minimum set of SAFES training software. The new software would consist of modules allocated between the two Mission Computers to minimize processing requirements, memory resources, and 1553 A bus traffic. The primary advantage of this candidate is that it is completely self-contained and uses the same connection to load the SAFES software as is used to load OFP software prior to flight (i.e., the 1553 A MUX bus or serial data port). Bus traffic is also reduced since those avionics devices being simulated by the training software will pass their parameters internally and not on the 1553 A bus. This assumes, of course, that avionic device simulation modules requiring bus parameters are located in the same Mission computer. If this is not the case, the parameters can be sent to the other Mission computer via the Inter Computer Communication (ICC) bus (a third 1553 A bus linking the two Mission Computers together).

The major disadvantage of this approach is that the current Version 5 F/A-18 Mission Computers are now operating at maximum capacity and there is no major cycle time left for training processing as shown in Section 3.0. A further disadvantage is that video images (vector and raster) would be extremely difficult to produce without available onboard storage devices capable of holding a large computer generated graphics data base.

When Version 6 AYK-14 computers become available, it will be feasible to run simulation software in the MC's. This capability would be further enhanced if two SCP's are installed in each MC. In this instance, it might be possible to run a full set of simulation software as well as the condensed OFP in the onboard MC's instead of the single candidate set necessary in the Version 5 AYK-14 computer. Of course, the video image data base storage problem would still exist.

4.2 Onboard With Pallet

This candidate is similar to that just described except that an external pallet mounted computer would be supplied to augment the capabilities of the Mission Computers. The MC's would contain a mix of condensed OFP software and SAFES training software. The pallet would also contain mass memory for storing training scripts, system configuration and initialization data, composite video data bases, and playback information. The external computer would communicate with the Mission Computers via the 1553 A bus links found in the nose wheel compartment of the F/A-18. In this case, since the Mission Computers are the bus controllers, the new mission computer software would permit modified bus traffic that allowed communication to take place between the MC's and the external computer. In addition, the pallet could contain video image generation hardware which would be used to stimulate the cockpit displays via weapons pod or FLIR composite video interfaces (for air-to-ground radar, FLIR, and TV weapons). Because of the existence of an external interface and pallet, an instructor station could also be added. Optionally, if technology warrants, Computer Based Training could be implemented in the pallet computer in lieu of an instructor station.

The feasibility of this approach can be illustrated by showing that a single Version 6 AYK-14 with one SCP would be capable of running the fairly complex F/A-18 flight simulation program developed at the Naval Air Test Center (NATC). The NATC simulation contains a representative air frame simulation model and models of the onboard systems associated with weapons delivery. It is estimated that SAFES software would require a similar sized software package. The NATC simulation requires about 224 Kbytes of memory. This is slightly less than a quarter of the 1024 Kbytes available in a single Version 6 AYK-14 computer. According to NATC information, the major cycle time of the F/A-18 simulation on a VAX 11/780 computer varies from 18.4 to 61.1 milliseconds with an average of 39.75 milliseconds. The difference is due to the number of targets introduced into the simulation and the radar scan rate selected. Memory and frame time characteristics of the NATC F/A-18 simulation are summarized in Table 4-2.

The ability of a single AYK-14 to host the NATC simulation is shown in Table 4-3 using the average simulation cycle time as a figure of merit in relation to the VAX 11/780 and AN/UYK-43 Naval Embedded Computer. The Version 5 AYK-14 is clearly underpowered for the task. However, a Version 6 AYK-14 with a SCP is nearly comparable to the VAX 11/780. The UYK-43 is superior to both the AYK-14 and VAX 11/780 computers. Based on this comparison, a single Version 6 AYK-14 would be capable of providing a fairly complex simulation of the F/A-18. This leaves the second AYK-14 for the condensed OFP software. Assumming that the pallet computer is another Version 6 AYK-14 (perhaps a spare MC to minimize system costs), a significant amount of processing power is available for the remaining SAFES software. Consequently, this approach appears to be quite feasible and practical.

Table 4-2 NATC F/A-18 Simulator Software Characteristics

Module	Memory (Kbytes)	Time (milliseconds)		
		Best	Worst	Avg
Air Data	22.5	2.1	4.8	3.45
Air Frame	41.0	10.3	13.4	11.85
INS	23.5	2.5	3.5	3.0
Radar (Digital)	64.5	2.6	18.5	10.6
SMS*	52.0	--	--	--
Target Simulator	20.5	0.9	20.9	10.9
Total	224.0	18.4	61.1	39.75

* SMS data is called intermittantly and not part of a frame cycle.

Table 4-3 Comparison of AYK-14, VAX 11/780, UYK-43 Computers

Module	AYK-14 Version 5	AYK-14 Version 6 With SCP	VAX11/780	UYK-43
Air Data	20.7	3.79	3.45	1.72
Air Frame	71.1	13.03	11.85	5.92
INS	18	3.3	3	1.5
Radar	63.3	11.61	10.55	5.27
SMS	--	--	--	--
Target Simulator	65.4	11.99	10.9	5.45
Total	238.5	43.72	39.75	19.88

4.3 Pallet System with Existing Mission Computer Software

This candidate is similar to the previously discussed approach except that the existing Mission computer software is not modified. The external computer (a UYK-43 or comparable) would be connected to aircraft 1553 A buses as described previously. The external computer would monitor bus messages and contain simulation software for many of the onboard systems. The corresponding onboard systems could then be powered down and not used during SAFES training. The significant advantage to this approach is that a high fidelity flight simulation software module can be located in the external computer since it can be sized to meet the demands of such a simulation. This approach also offers the advantage of not requiring the OFP software to be reloaded after a training session. This minimizes the impact of SAFES training on mission readiness which may be a critical issue during deployment.

As in the previous case, with an external computer composite video sources (SMS, FLIR, and radar) can be simulated. Also, the creation of an out-of-cockpit view should prove feasible since the external computer could drive a helmet mounted display. Since the helmet mounted display would only be used while the aircraft is parked, there is likely to be no objection to its use by the Fleet. Additionally, audio and physical cues (e.g., g-seat) could be provided (this would also be true for the Onboard With Pallet candidate).

4.4 Pallet System With Mission Computers Disabled

In this candidate, the Mission Computers and the simulated avionics devices are powered down. The external pallet mounted computer provides all 1553 A bus control information and control. It incorporates all the desirable features of the previously described candidate as well. In many respects, this candidate represents the future of SAFES-like embedded training systems when vastly more powerful avionics computers become available to aircraft designers, and all pallet capabilities can be hosted in the Mission Computers.

4.5 Built-in Test SAFES Capability

This approach is the most futuristic of the SAFES candidates considered in this study. It is based on the incorporation of training related functional modules implemented in all avionics devices required for training. These modules could be placed on VLSCI chips during their production. In a sense the aircraft avionics systems become a powerful distributed processing system linked together for SAFES training purposes. The clear disadvantage of this candidate, is that it does not exist and will not exist until the value of using modern aircraft digital cockpits for training has been demonstrated and has become relatively commonplace.

4.6 Recommended SAFES Configuration

The SAFES concept described in Section 4.2 (Onboard with Pallet) with SAFES training software residing in both the MC's and an external pallet mounted computer appears to be the most reasonable approach to pursue with today's technology. The F/A-18, Pallet, and Interface components are discussed in the next three sections.

4.6.1 F/A-18 Subsystem and Configuration

A more detailed system block diagram for this concept is shown in Figure 4-1. The left side of the figure represents F/A-18 subsystems involved with SAFES and the software modules residing in the two MC's. The F/A-18 flight computers (FCCA and FCCB) are retained in order to have pilot HOTAS inputs placed on the 1553A bus (stick and throttle position, rudder commands, etc.) for use by SAFES software.

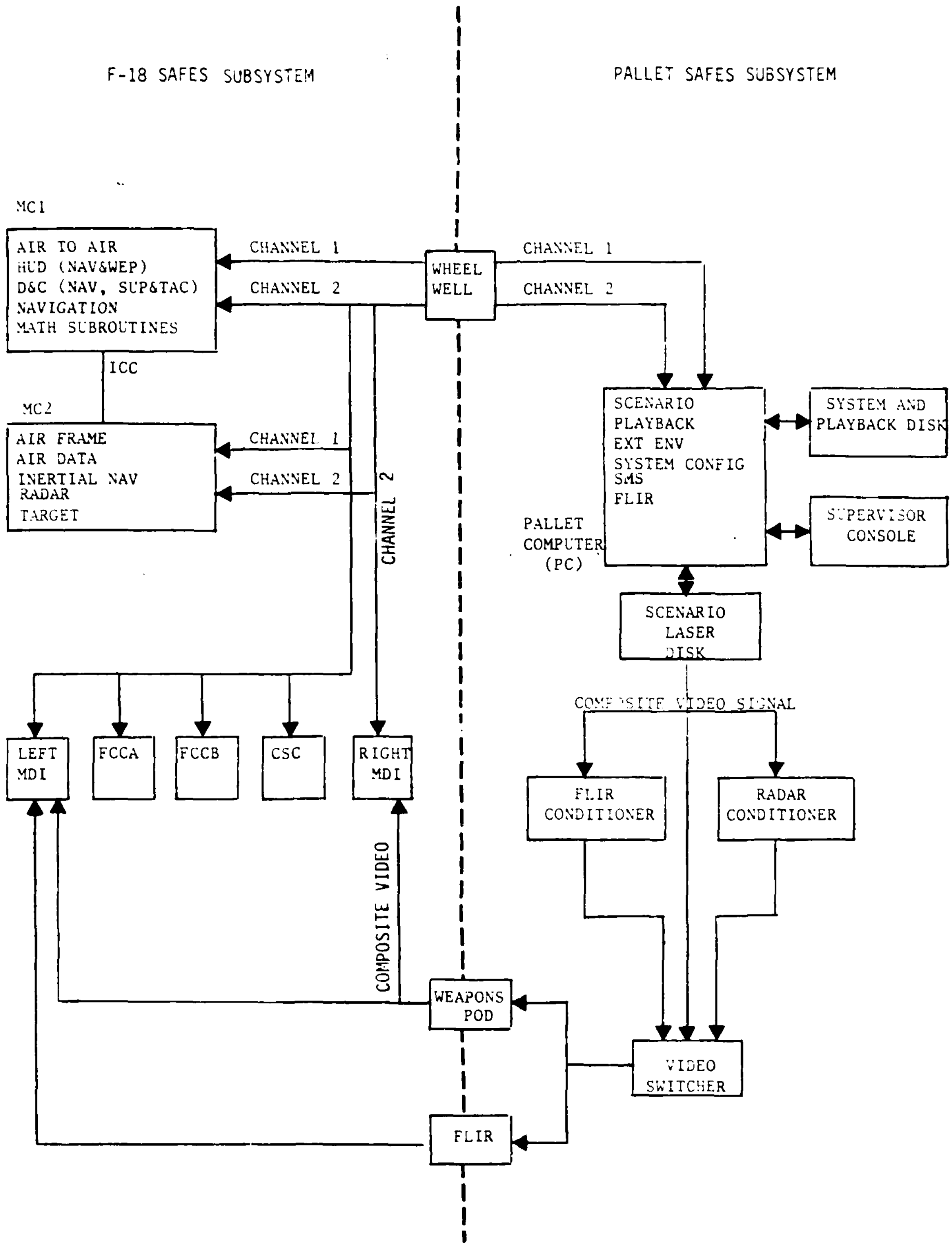


Figure 4-1 SAFES System Overview Diagram

The two MDI's will send display information to the HUD display not shown on the Figure. The communication system (CSC) functions such as TACAN may be simulated. All other aircraft systems and avionics are not used and powered down.

The software modules shown in MC 1 represent a condensed version of the flight software containing only those functions required to support the simulation software. MC 2 will contain selected modules for flight simulation. These modules can be loaded into the MC's via the 1553 A serial data bus. Based on previously discussed cycle times, these modules will use virtually all of the processor cycles available during a 50 millisecond simulation cycle in both MC's. The remainder of the simulation software will run on the exernal Pallet Computer (PC) shown on th· right of Figure 4-1.

The 1553 A bus traffic will be controlled by MC 1. Bus traffic will conform to the existing set of messages defined for the F/A-18 when in a flight ready mode as much as possible. Some modifications will be necessary to support modules requiring an interface that are running is separate processors. To increase available bus bandwidth, traffic for devices not needed for the training scenario will be dropped from the simulation software.

The ICC 1553 A bus between the two Mission Computers will transmit information needed by the software in MC 1 and generated in MC 2. Any bus traffic from the two main 1553 A buses (Channel 1 and Channel 2) required by MC 2 will be taken directly from these buses.

Composite video information will be supplied from the SAFES pallet via a weapon pod connection ordinarily used for TV guided weapon input or a FLIR connection. The weapon pod connection will supply video to the left MDI and the FLIR connection will supply video to the right MDI. The video information will be stored on a laser disc controlled by the pallet computer. In this way, a large number of highly detailed scenes can be displayed to the pilot during a SAFES training session representing air to ground radar images, FLIR images, and TV weapon scenes.

4.6.2 Pallet Subsystem Configuration

The SAFES pallet subsystem is shown on the right side of Figure 4-1. It is composed of a Pallet Computer (PC), a system and playback disc, a laser disc for composite video generation, a supervisor console, two composite video signal conditioners, and a video switch.The PC is the central component of the SAFES pallet. The bulk of the training software resides in this computer. It interfaces directly with the two main 1553 A buses, and supplies control data to the external units and MC software.

The System Configuration module in the PC is responsible for transferring the MC software from the systm disc to the two MC's via the 1553 A buses. The Scenario module initializes the simulation software for a given training script, and allows dynamic changes to be introduced into the simulation from the Supervisor Console. The Playback module monitors bus traffic and stores any data required to generate a playback of a given script with pilot responses included. In playback mode, the playback software takes control of the 1553 A buses and generates whatever traffic is necessary to recreate the training scenario (it can also drive a playback for the supervisor).

The External Environment module supplies control data to the laser disc, when requested by the Radar, SMS, or FLIR simulation modules. The latter modules provide the characteristics of the video data to be retrieved from the laser disc.

4.6.3 F/A-18 and Pallet Subsystem Interface

The interface between the F/A-18 and Pallet Subsystems is through the two main 1553 A buses via a wheelwell connector readily accessible to the outside world. Composite video signals are transmitted from the Pallet to the F/A-18 through video bus connectors existing in the weapons pod, for TV guided weapons, and the FLIR.

Message traffic modifications to the 1553 A buses will mainly consist of supplying radar air-to-air vector graphic data to the display module in MC 1 from the radar module in MC 2 over the ICC. The remaining communication messages should be identical to those existing in the flight software. It should be noted that the SAFES software module allocation shown in Figure 4-1 may be modified during the development phase to satisfy timing and sizing constraints unknown at this time. Also, unused traffic messages on the 1553 A buses will be deleted when SAFES software is executed.

5.0 SAFES TRAINING SCRIPTS

In many respects SAFES goes beyond what is regarded as conventional flight simulation and crosses over into the relatively new field of Computer Based Training Systems (CBTS), particularly if an instructor station is not included in the baseline SAFES. In classic CBTS, the production of an interactive computer lesson is guided by the learner's knowledge, skills, understanding, expectations, and motivation. The learner's education needs, not the computer hardware or software, determine the nature of the lesson. In SAFES, this distinction is not so clearly defined since the training system is also composed of many of the system elements to be learned. To maintain the proper perspective on the computer based SAFES, it should be remembered that the computer is neither instruction nor a method of instruction; it is merely a vehicle of instruction. Furthermore, the SAFES computer will offer powerful features for facilitating learning such as instructor-like interaction with the pilot. Therefore, the developement of SAFES training scenarios should be much more than borrowing procedures from existing training manuals or flight procedures. The conversion of these practices into effective CBTS training will be a new skill developed by SAFES. However, in order to begin this process, it will be necessary to examine conventional flight training procedures and select several for SAFES. Two examples of scenarios that might be considered for this task are discussed in the following paragraphs.

5.1 Air-to-Air Threat Avoidance

In Section 2, the Air-to-Air Threat Avoidance task was identified as one of the most critical combat tasks suitable for computer image generation training since most of the visual threat information is displayed symbolically on the aircraft displays. The F/A-18 Simulator Briefing Guide (Ref. 10) describes several threat avoidance training scenarios that depend on radar acquisition of the threat. Pilot flight conduct is judged on (1) how well he carries out radar search and target identification (2) geometry control during approach (3) proper communication terminology (4) formation control (5) recognition of the target (6) offensive while passing the target (7) shots during the pass, and (8) lookout doctrine.

This training task does not require video (raster) imagery on any of the cockpit displays. Thus, it would will focus SAFES feasibility demonstration efforts on scenario preparation and software development. This scenario should probably be simplified to exclude item 3 since no voice recognition capability is envisioned for SAFES.

5.2 Aircraft Emergency Procedures Practice

The F/A-18 Simulator Briefing Guide provides a number of emergency training scenarios for SAFES demonstration. The most suitable tasks for SAFES are NATOPS Checks. An example of such a task would be to have the aircraft takes off and proceed under instrument flight rules to its destination. Emergencies that can be selected by the simulator instructor (or randomly chosen by the software executive) are shown in Table 5-1.

Table 5-1 NATOPS Check Scenario

Flight Regime	Emergency Procedure	Comments
Takeoff	Hot Start	15 seconds to respond
	Fire on Start	15 seconds to respond
	Low Oil Pressure on Start	15 seconds to respond
Takeoff Roll	Loss of Thrust	15 seconds to respond
	EGT High	15 seconds to respond
	Blown Tire	15 seconds to respond
Enroute Segment	Single Engine Flameout	15 seconds to respond
	Generator Failure	15 seconds to respond
	MC 1 or MC 2 Failure	15 seconds to respond
	INS Failure	15 seconds to respond
	Tank Pressure Caution	15 seconds to respond
	Flight Control System Failure	Comply with NATOPS
Landing Approach	Anti-skid Caution	15 seconds to respond
	Landing Gear Fails to Extend	15 seconds to respond
	Batt Switch Caution	15 seconds to respond
	Hyd 1A or 1B Failure	15 seconds to resppnd
	Flight Control System Failure	Comply with NATOPS
	L or R AMAD Caution	"
	L or R Oil Pressure Low	"
	Unsafe Gear Down	"
	AV Air Hot	Follow Procedures
	Fixed Gains or Flap	15 Seconds to respond
	Flaps Off Caution	15 Seconds to respond
Postlanding	L or R AMAD Caution	"
	Fuel Hot Caution	"
	Loss of NWS	"
	Engine Fire	Comply with NATOPS

5.3 SAFES Training Scenario Definition Approach

A three part plan will be used to translate F/A-18 flight simulator tasks similar to those just described into training scenarios suitable for SAFES implementation. The first step consists of initial planning. That is, the target population is characterized, overall goals are formulated, the overall task is analysed, prerequisite skills are designated, and an initial set of evaluation measures to assess pilot performance are generated.

After initial planning, each subtask can be designed one at a time. Pilot feedback is needed during this phase since it is not clear how pilots will react to the subtasks. This will also increase the likelyhood of pilot acceptance in the final product as well.

Finally, the subtasks will be integrated into a central framework providing initiation, freeze, and abort command inputs if necessary. These training "scripts" will then be merged with the required flight simulation software to form the SAFES package.

6.0 Summary and Recommendations

The technical research conducted during this phase of the SAFES study has shown that the F/A-18 Hornet is a suitable candidate for demonstration of a SAFES capability and development of the necessary technology and training software. This study has also shown that critical pilot skills ranging from air intercept to cockpit switchology can be simulated in modern aircraft with computer driven state-of-the-art displays. In particular, the F/A-18 avionic systems, computers, and displays were examined in detail. The results of this examination revealed that the F/A-18 architecture (pilot controls, weapon systems, flight computers, navigation and weapons computers, all linked by serial digital busses) will support the SAFES concept.

A SAFES configuration suitable for the F/A-18 was identified and consisted of a mix of SAFES training software and Operational Flight (OFP) software residing in both Mission Computers augmented by additional simulation software residing in an external pallet mounted computer. The external computer would communicate with the on board computers through a 1553 A MUX bus connector available in the nose wheel compartment. The external computer would also control the injection of composite video images into the aircraft displays via weapons pod connectors.

Based on the above findings, it is recommended that the next SAFES project phase address several key technical issues in detail. The first issue deals with identifying OFP software modules and defining how they would interface with SAFES training software. A second technical issue is the ability of the F/A-18 Mission Computers to send graphic commands to the cockpit displays so that radar digital images can be simulated by SAFES. A third issue is the injection of composite video images into the cockpit displays from an external source.

Given that these three issues are successfully addressed, the next phase of SAFES should also include preparation of a simple SAFES training scenario for demonstration purposes. Based on Fleet pilot and instructor response to this demonstration, a decision to develop a more complete SAFES capability could be made with confidence.

APPENDIX A

F/A-18 DISPLAY CHARACTERS

BIT NUMBER

SINGLE WORD OP CODES

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15		
0	0	0	0	0	0	X	X	X	X	X	X	X	X	X	X	X	NO OPERATION	NOP
1	0	0	0	0	1	0	SG	MODE			A	DEST					MODE DESIGNATOR	MDD
2	0	0	0	1	0	0	X	X	X	X	X	X	X	4	2	1	INTENSITY	INT
3	0	0	0	1	1	0	X	S	-DASH-			-GAP-					LINE STRUCTURE	LST
4	0	0	1	0	0	#	INS	256 -# OF TIMES-								1	REPEAT	RPT
5	0	0	1	0	1	P	512 -TRANSLATION-									1	TRANSLATE X	TNX
6	0	0	1	1	0	P	512 -TRANSLATION-									1	TRANSLATE Y	TNY
7	0	0	1	1	1	180 Θ											ROTATE	ROT
8	0	1	0	0	0	1024 -REL ADDRESS-										1	INCLUSION BORDER	INB
9	0	1	0	0	1	1024 -REL ADDRESS-										1	OCCLUSION BORDER	OCB
10	0	1	0	1	0	1024 -REL ADDRESS-										1	RECTANGLE	RCT
11	0	1	0	1	1	X	X	X	X	X	X	X	X	X	X	F	FLAG CONTROL	FLC
12	0	1	1	0	0	1024 -ABS ADDRESS-										1	JUMP ABSOLUTE	JPA
13	0	1	1	0	1	1024 -REL ADDRESS-										1	JUMP RELATIVE AND LINK TO PATCH	JLP
14	0	1	1	1	0	1024 -REL ADDRESS-										1	JUMP RELATIVE	JPR
15	0	1	1	1	1	1024 -REL ADDRESS-										1	JUMP RELATIVE CONDITIONAL	JPC

APPENDIX A

F/A-18 DISPLAY CHARACTERS

BIT NUMBER

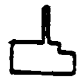
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31

DOUBLE WORD OP CODES — REL ADDRESS

	0–4	5–15	16–20	21–31
16	1 0 0 0 0	SIZE | R | X | - MASC II -	X X X X X	1024 SINGLE A/N SAN 1
17	1 0 0 0 1			X,Y Preset
18	1 0 0 1 0	SIZE | 256 - WORD COUNT- 1	X X X X X	1024 RADAR A/N RAN 1
19	1 0 0 1 1	SIZE | V/H | 128 - WORD COUNT - 1	32 - GAP - 2	1024 TYPEWRITER A/N TAN 1
20	1 0 1 0 0			Preset Alpha
21	1 0 1 0 1	X X | S/C | 128 - WORD COUNT - 1	X X X X X	1024 VECTOR VTR 1
22	1 0 1 1 0	B/C | V/F | X X X X X X | 4 WORD COUNT 1	X X X X X	1024 CONIC CNC 1
23	1 0 1 1 1	X X X | 128 #OF OP CODES 1	X X X X X	1024 SET SET 1
24	1 1 0 0 0	SIZE | H/A | - DASH - | - GAP -	B | W/NT | HC/AG | FORMAT	1024 PITCH SCALE PIT 1
25	1 1 0 0 1	X X | MIN/MAJ | DEG/MAJ.T	C/DC | OR | TB | PB	1024 COMPASS SET CMP 1
26	1 1 0 1 0	X X | MIN/MAJ | ML | SCALING	BP | N/NN | W | FORMAT	1024 SCALE SCL 1
27	1 1 0 1 1	SIZE | B | X | TR | 64 -TICK LENGTH - 2	32 SHADING 2	1024 ADI ADI 1
28	1 1 1 0 0	1024 - WORD COUNT - 1	X X X X X	1024 SG DIRECT SGD 1
29	1 1 1 0 1	SIZE | #BAR | A R | 32 - TICK LENGTH - 2	X | X | X | X | X	1024 RETICLE RCL 1
30	1 1 1 1 0			SPARE
31	1 1 1 1 1			SPARE

APPENDIX B

F/A-18 DISPLAY INSTRUCTION OP CODES

Octal Code	Character	Octal Code	Character
000	Space	030	X
001	A	031	Y
002	B	032	Z
003	C	033	\
004	D	034	
005	E	035	
006	F	036	
007	G	037	
010	H	040	
011	I	041	"
012	J	042	?
013	K	043	:
014	L	044	#
015	M	045	-
016	N	046	+
017	O	047	'
020	P	050	(
021	Q	051	)
022	R	052	*
023	S	053	%
024	T	054	,
025	U	055	•
026	V	056	.
027	W	057	/

APPENDIX B

F/A-18 DISPLAY INSTRUCTION OP CODES

Octal Code	Character	Octal Code	Character
060	0	110	▬
061	1	111	
062	2	112	▯
063	3	113	▭
064	4	114	◇
065	5	115	
066	6	116	
067	7	117	
070	8	120	
071	9	121	| |
072	-	122	⬡
073	→	123	×
074	↓	124	↑
075	↑	125	
076	←	126	▭
077	Λ	127	
100	>	130	
101	<	131	
102	V	132	+
103		133	○
104		134	◇
105	●	135	
106	☆	136	
107	▬	137	◁

APPENDIX B

F/A-18 DISPLAY INSTRUCTION OP CODES

Octal Code	Character	Octal Code	Character
140	▷	170	8
141	◫	171	9
142	⬠	172	▭
143	┼	173	▯
144	_ _	174	—
145	‿w‿	175	⋂
146	[	176	—
417	o	177	—
150	⏃		
151	X		
152	✕		
153	^		
154	⊙		
155	—		
156	∝		
157	|		
160	0		
161	1		
162	2		
163	3		
164	4		
165	5		
166	6		
167	7		

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